Synopsis and Trends in the Physical Environment of Baffin Bay and Davis Strait

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ABSTRACT

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A review of trends in physical properties of Baffin Bay and Davis Strait based on published literature, analyses of archived long time series data and interpretation of recent data are presented. General physical characteristics of Baffin Bay and Davis Strait are also described, including the general circulation and a summary of freshwater sources.

The time series presented and analyzed are typically characterized by high inter-annual variability but there is evidence of freshening on the Baffin Island Shelf since 1980, and warming of Baffin Bay intermediate waters over the last 50 years. Input into Baffin Bay through Barrow Strait/Lancaster Sound has become warmer and more saline over the last decade, and there is also the suggestion of a downward trend ($p=0.13$) in the volume and freshwater input here of 4% per year over this same period, but the 12 year data set is too short to confidently establish that these trends in Barrow Strait are anything more than natural variability There are insufficient published data to assess trends in other Baffin Bay/Davis Strait ocean inputs, except for evidence of increasing meteoric water input from the Greenland ice sheet. Accelerating mass loss will likely make it a significant freshwater contributor by 2050 that will decrease salinity of the Baffin Island Current and therefore the Labrador Current further downstream.

Finally, there has been strong atmospheric warming on the western side of Baffin Bay (2 to 3°C/decade) since the late 1990’s and coincident rapid decline of sea ice cover in all seasons (Peterson and Pettipas, 2013).

RÉSUMÉ

Hamilton, J.M., and Wu, Y. 2013. Synopsis and trends in the physical environment of Baffin Bay and Davis Strait. Can. Tech. Rep. Hydrogr. Ocean Sci. 282: vi + 39 p.

Un examen des tendances liées aux propriétés physiques de la baie de Baffin et du détroit de Davis, fondées sur des publications scientifiques, des analyses de longues séries chronologiques de données archivées et sur l'interprétation des données récentes, est présenté. Les caractéristiques physiques générales de la baie de Baffin et du détroit de Davis sont également décrites, notamment le régime de circulation générale et un résumé des sources d'eau douce.

Les séries chronologiques présentées et analysées sont habituellement caractérisées par une grande variabilité interannuelle, mais il y a des preuves de dessalure sur le plateau de l'île de Baffin depuis 1980 et des preuves de réchauffement des eaux intermédiaires de la baie de Baffin au cours des 50 dernières années. Les apports dans la baie de Baffin provenant du détroit de Barrow et du détroit de Lancaster sont devenus plus chauds et plus salins au cours de la dernière décennie, et on y observerait également une tendance à la baisse (p=0,13) du volume et des apports d'eau douce, à raison de 4 % par année, au cours de la même période, mais la période de référence (12 ans) de l'ensemble des données est trop courte pour établir avec confiance que les tendances observées dans le détroit de Barrow ne sont rien de plus qu'une variabilité naturelle. On ne dispose pas de suffisamment de données publiées pour évaluer les tendances liées aux autres apports d'océan dans la baie de Baffin et le détroit de Davis, sauf une preuve de l'augmentation des apports d'eau météorique provenant de la nappe glaciaire du Groenland. Une perte accélérée de la masse aura probablement pour effet de contribuer de manière importante aux apports d'eau douce d'ici 2050, ce qui réduira la salinité du courant de la baie de Baffin et, par conséquent, le courant du Labrador un peu plus loin en aval.

Enfin, on observe un réchauffement atmosphérique important dans la partie ouest de la baie de Baffin (de 2 à 3 °C par décennie) depuis la fin des années 1990 ainsi qu'un déclin rapide simultané de la couverture de glace de mer pour toutes les saisons (Peterson et Pettipas 2013).

1.0 INTRODUCTION

Baffin Bay is a semi-enclosed ocean basin between Baffin Island and Greenland that connects the Arctic Ocean and the Northwest Atlantic (Fig 1), providing an important pathway for exchange of heat, salt and other properties between these 2 oceans. To the south the connection with the Atlantic is through Davis Strait, which is over 300 km wide and 1000m deep. Baffin Bay's direct connection to the Arctic Ocean is far more restricted, being just 3 relatively small passages through the islands of the Canadian Arctic Archipelago (CAA). Arctic water also enters Baffin Bay/Davis Strait via the West Greenland Current which flows northward along the western coast of Greenland. Melting ice sheets, changing sea ice conditions and changing weather also influence oceanographic conditions in Baffin Bay and Davis Strait.

Trends and variability in the freshwater and heat input into the western North Atlantic via Baffin Bay/Davis Strait is of special interest because of the potential impact this input may have on global ocean circulation. Higher volumes of lighter, fresher water entering the Labrador Sea would increase stratification, with potential impact on the thermohaline circulation. The sinking of atmospherically cooled surface water in the Labrador Sea (the northwest arm of the North Atlantic) provides one of the driving forces for the "global ocean conveyor belt" which is vital in transporting heat and salt to northern latitudes. However, freshwater entering Baffin Bay is somewhat confined to the ocean's margins as part of a cyclonic circulation pattern, a principal component being the Baffin Island Current (BIC) that flows southward along Canada's shelf and slope. Therefore, there is a potential for changes in this freshwater flux to impact the western North Atlantic ecosystem and fisheries by altering the physical properties of productive east coast banks and slope areas.

Here, a review of the physical environment of Baffin Bay and Davis Strait is presented with a focus on trends identified in the various data that are analyzed for this report, and those identified in the literature. An emphasis is on the freshwater budget for reasons outlined above, but trends in water properties and atmospheric conditions impacting the ocean environment are also described. It is hoped that identified trends will be useful in providing a baseline upon which to compare future changes, and in some cases may be useful in projecting future conditions so that climate change impacts can be assessed.

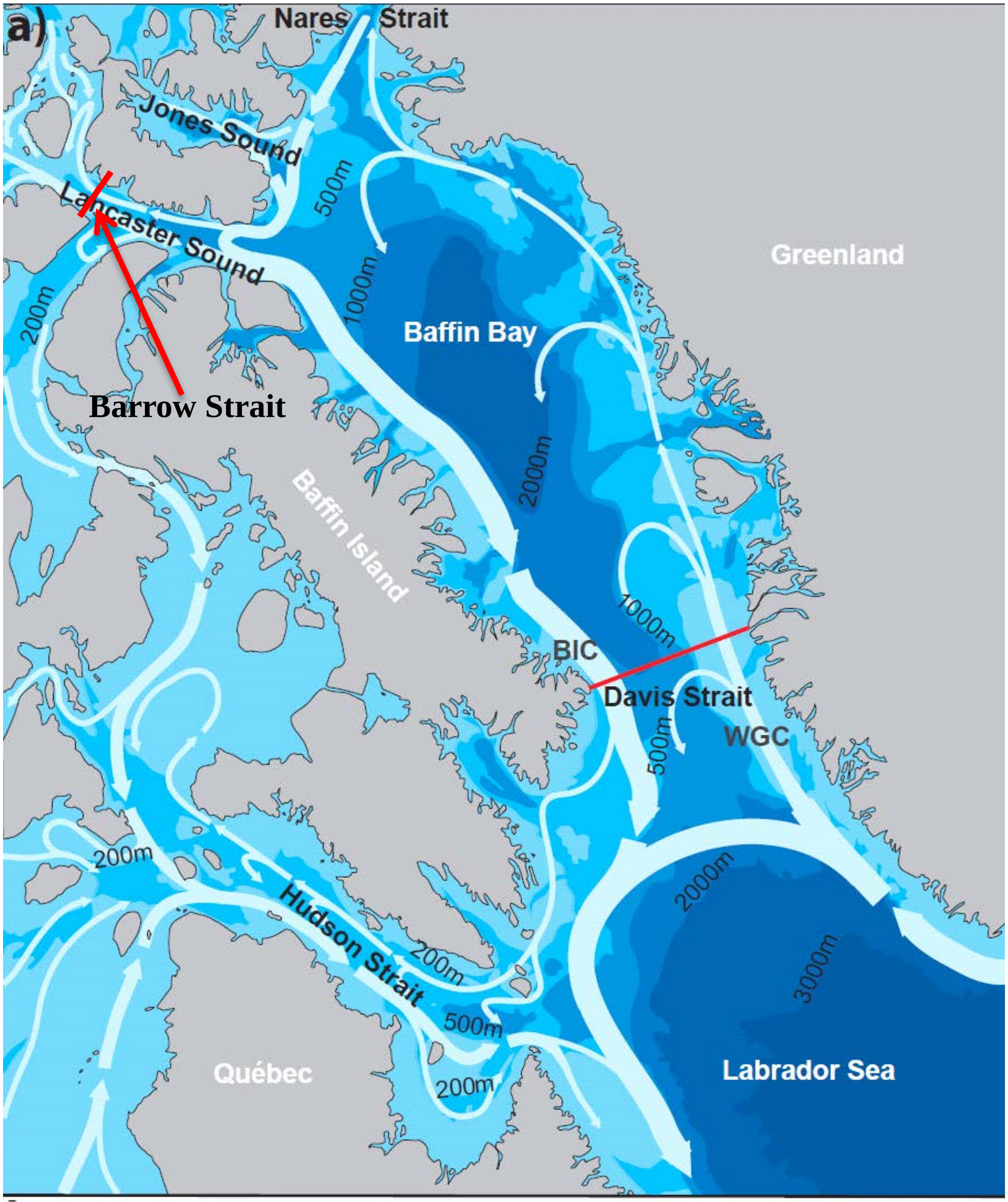

Figure 1. General circulation and bathemetry in Baffin Bay and Davis Strait (from Curry et al., 2011). The red lines indicate the location of the mooring array in Barrow Strait described in Peterson et al. (2013), and the mooring array across Davis Strait described in Curry et al. (2011).

2.0 CIRCULATION IN BAFFIN BAY/DAVIS STRAIT

The cold and fresh Arctic waters that enter northern Baffin Bay through Nares Strait, Jones and Lancaster Sounds form the broad, surface-intensified BIC, an important component of the circulation in Baffin Bay (Tang et al., 2004; Cuny et al., 2005; Curry et al., 2011). The BIC flows southward along the east coast of Baffin Island and into the western half of Davis Strait, eventually feeding the Labrador Current (Figure 1). Along the west Greenland slope and shelf, the West Greenland Current (WGC) transports cold, fresher Arctic water northward as a continuation of the flow from the East Greenland Current (EGC), and relatively warm and salty waters from the Irminger Sea further offshore. The majority of this Irminger Sea water circulates cyclonically around the northern Labrador Sea constrained by the shallowing bathymetry of Davis Strait, although a portion continues northward along the slope into Baffin Bay as a continuation of the WGC (Bourke et al., 1989). Fresher Arctic waters over the shelf and slope also continue northward through eastern Davis Strait to as far north as 78 °N, then turn west to join the BIC (Rabe et al., 2010). The mean current field in the upper 200m, derived from a numerical circulation model (Wu et al., 2012) is shown in Figure 2. This provides some of the finer flow details such as an anti-cyclonic circulation cell in western Davis Strait between 64^o 30' N and 66^o 30' N, that is also found in field observations of both Tang et al. (2004) and Curry et al. (2011).

In the late 1930s, investigators first documented the southward flow on the western side of Baffin Bay and northward flow on the eastern side (Kiilerich, 1939). Since then, there have been a number of field studies that provide more details about the circulation in Baffin Bay (e.g. Collin and Dunbar, 1964; Fissel, 1982; Marko et al., 1982; Ross, 1990a, 1990b, 1991, 1993; Bourke et al., 1989; Cuny et al., 2005; Curry et al., 2011). Tang et al. (2004) studied the variability of the circulation in Baffin Bay and transports through Davis Strait from current meters deployed across Davis Strait and across the slope around the Bay in 1981-1989. They found that the currents in summer and fall tend to be stronger than those in winter and spring at all depths. Using a three-dimensional circulation model, Dunlap and Tang (2006) simulated the mean circulation in summer and found that the major factor influencing the BIC was the inflow from the northern channels connecting the Arctic Ocean with Baffin Bay.

Modeled circulation at the 500m level (Wu et al., 2012) not shown here, indicates that the deeper core of the WGC (containing warmer, saltier Irminger Sea water) reaches the southern end

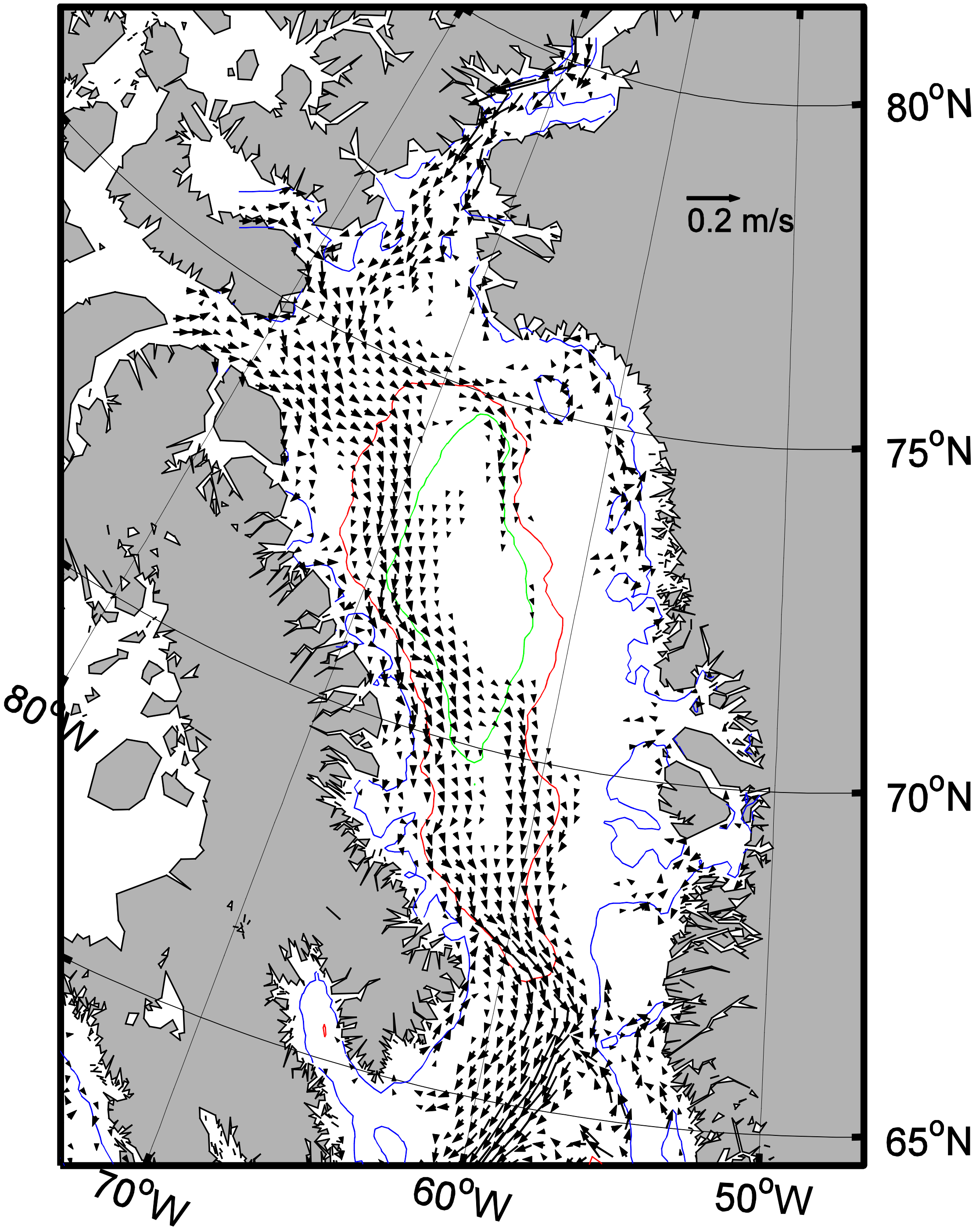

Figure 2. Averaged model currents in the upper 200 m. Velocities smaller than 0.02 m s^{-1} are not plotted. The contour lines are the bathemetry; blue-200 m, red-1000 m and green-2000 m.

of Davis Strait at about 66^o 30' N before the majority turns southwest towards the Labrador Sea in summer. This model result is consistent with observations presented by Tang et al (2004) based on a 3-year current meter array deployed along 66^o 15'N. In winter, the model indicates the northern limit of the core of the WGC is at 64^o 30' N, which is also consistent with (Tang et al., 2004) who did not observe a strong southward winter current in eastern Davis Strait.

3.0 BAFFIN BAY/DAVIS STRAIT OCEAN INPUTS

Freshwater enters Baffin Bay by 3 principal pathways. Arctic Ocean freshwater enters the western North Atlantic through the passages of the CAA mostly in liquid form. An equivalent amount enters by way of the WGC having exited the Arctic Ocean through Fram Strait. A third, rapidly increasing freshwater input is Greenland ice sheet melt water and solid ice discharge.

3.1 Transports through the Canadian Arctic Archipelago

Recent efforts have been made to quantify the volume, freshwater and heat transports through the 3 passageways that connect the Arctic Ocean to the Northwest Atlantic. The most comprehensive of these is a 13 year time series from a moored instrument array that was maintained across eastern Barrow Strait at the eastern end of the Northwest Passage from 1998-2011. The resulting freshwater transport time series (from Peterson et al., 2013) is shown in Figure 3.

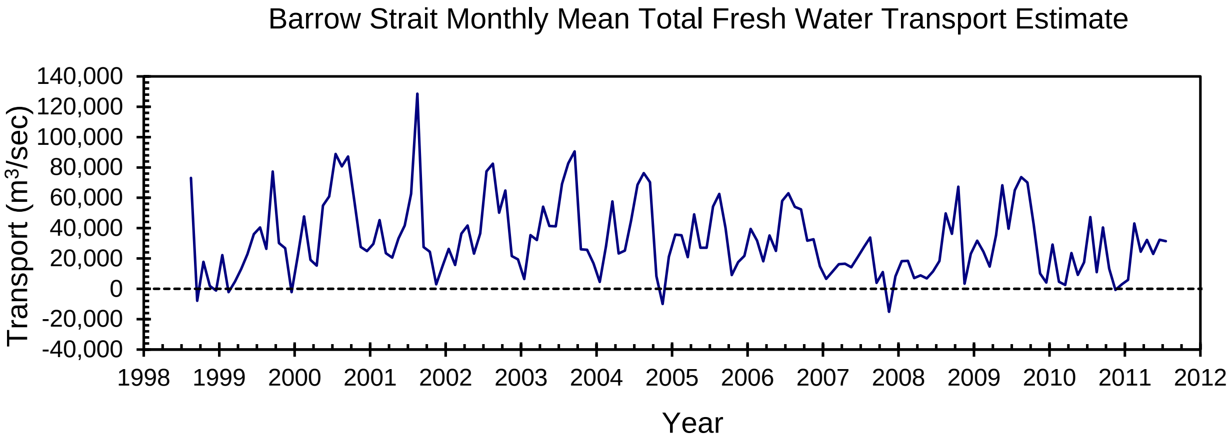

Figure 3. Thirteen year time series of freshwater transport through Barrow Strait from instrumented mooring data (Peterson et al, 2013).

The overall mean freshwater transport is 0.032 ± 0.010 Sv (1 Sv = 10^6 m^3s^{-1}) plus an additional 6% for the freshwater exported as ice (Peterson et al., 2013). This is equivalent to twice the volume transport of the St. Lawrence River. There is high seasonal variability in these transports. Figure 4 reveals a summer peak in transports (July-September) that is about 3 times higher than the minimum seen in November-December. The volume transport is very highly correlated (r^2 = 0.98) with the freshwater transport and about 15 times larger 0.46 ± 0.09 Sv).

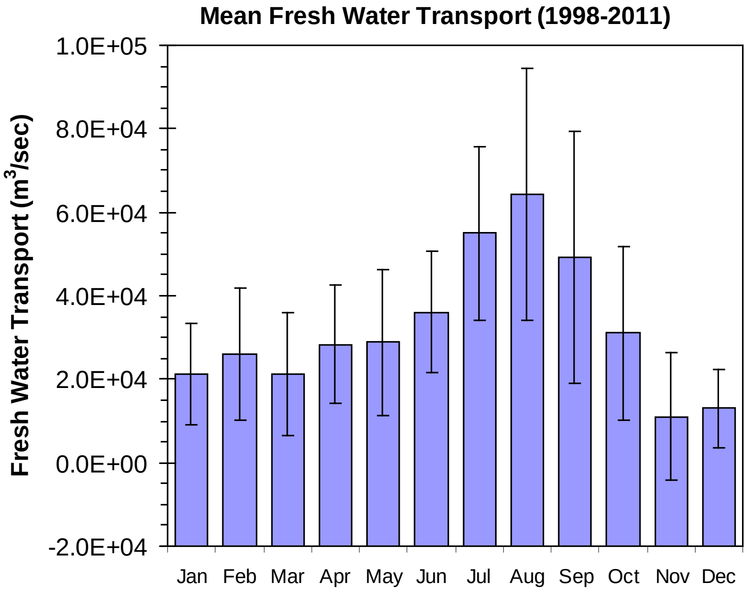

Figure 4. Monthly mean freshwater transports (± 1 sd) derived from 13 years of instrumented mooring data.

Figure 5 highlights the extent of the inter-annual variability in the transport. There is also the suggestion of a trend towards lower transports through Barrow Strait over the 12 years shown. The linear regression line shown can account for 21% of the variability in the annual means, but this trend is only significant at the 87% confidence level (p = 0.13 in Figure 5).

Instrumented mooring measurements have also been used to derive transport estimates through the other 2 main CAA passages. Melling and Agnew (2008) estimate a mean volume transport of 0.3 Sv for Cardigan Strait-Hell Gate, while Munchow and Melling (2008) give a mean volume transport below 30m in Nares Strait of 0.57 ±0. 09 Sv based on 3 years of measurements. If we crudely account for the missing top 30m in their estimate by assuming that the transport in that upper layer is proportional to the portion of the strait cross-sectional area it represents, then the total volume transport for Nares Strait is about 0.7 Sv.

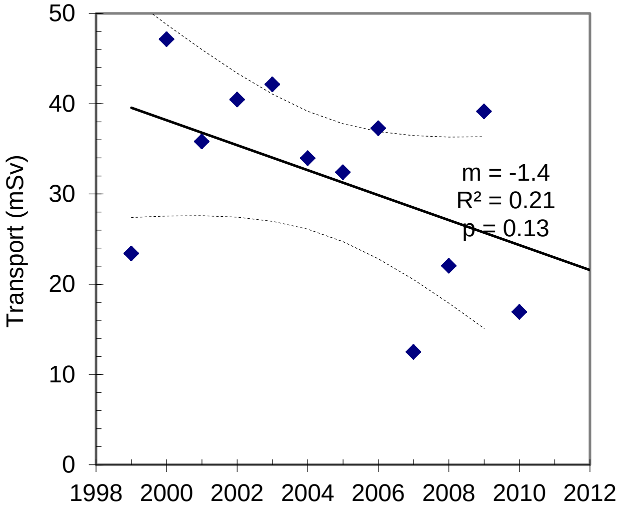

Figure 5. Annual mean freshwater transports through Barrow Strait from 1999 to 2011, with a least squares fit to the data showing a trend to lower transports of -14 mSv/decade. 95% confidence limits are shown as the dashed curves.

These annual mean transport estimates for each of the 3 passages can be summed to give a total mean volume transport through the CAA of about 1.5 Sv. If it is assumed that the 15:1 volume to freshwater ratio seen in Barrow Strait is reasonable for Nares Strait and Cardigan Strait-Hells Gate, a total mean freshwater transport of 0.1 Sv is estimated for the CAA. But there is little observational evidence to assess whether the high variability in transports through these passages is in phase. The only available concurrent measurements are for Nares Strait and Barrow Strait from summer 2003 to summer 2006. Munchow and Melling (2008) indicate their least squares fit to the Nares Strait data time series shows a statistically significant 20% increase in transport over this 3 year period. A similar calculation from the Barrow Strait data set shows no trend in the transport there over the same period. A longer period of comparison is needed to confidently assess any phase relationship in the transports through the 3 passages based on data. However, recent results from a 10 year computer simulation of the Arctic Ocean using a 6 km resolution, coupled ocean sea-ice model (Lu et al., 2013) suggest that the volume transport through Barrow Strait, Nares Strait and Davis Strait are tightly in phase, and these are 180° out of phase with the volume transport through Fram Strait. The relative phase of the freshwater transports through these gateways is not as tight in their result, but there is less confidence in these modeled freshwater fluxes due to difficulty in accurately defining the salinity field in their model.

Forcing mechanisms for the CAA Through-flow

Peterson et al. (2013) show that half of the observed variability in the transports through Barrow Strait on monthly to inter-annual time scales can be explained by variability in alongshore winds in the Beaufort Sea. Northeastward winds there raise the sea level along the western coast of the archipelago to create a sea surface slope from the eastern Beaufort to the Atlantic which drives the flow through the Northwest Passage. Their analysis shows no statistically significant similar mechanism when transport variability was compared to variability in Baffin Bay winds.

In the modeling study of McGeehan and Maslowski (2012) variability in transports is also linked to sea surface slope variability, but they suggest that at least half of the slope anomaly is due to sea surface height variability in Baffin Bay caused by seasonality in the WGC. This mechanism acting alone leads to the prediction of a maximum volume transport through Barrow Strait in March-April which is inconsistent with the observations. Their model does correctly predict the timing of the maximum freshwater transport as occurring in August, but predicts that the volume transport peak occurs 5 months earlier, which is inconsistent with the estimates derived from the moored observations. Those observations show the freshwater and volume transports to be very highly correlated, with no lag.

Lu et al. (2013) conclude that sea level control mechanisms in the Beaufort Sea and in Baffin Bay both work to drive flow through the CAA, with their relative importance being seasonally dependent. They suggest that the sea level control mechanism on the eastern side of the CAA may be related to wind stress in the northern Labrador Sea and Davis Strait.

Trends in Barrow Strait water and ice properties

The long time series of mooring data from Barrow Strait also provide an opportunity to look for trends in water and ice properties at this important connection between the Arctic Ocean and Baffin Bay/Davis Strait. Results from 10 years of data collected at the 150m contour on the south side of Barrow Strait are shown in Figure 6. There is a trend of increasing salinity at both the 40m and 145m levels, but not at high statistical confidence in several cases. At 40m the increase in the annual mean is +0.24 psu/decade (p=0.18, or 82% confidence of a positive trend), with the strongest (and statistically significant at the 95% level) seasonal increase occurring in late summer (+0.51 psu/decade). Near-bottom (145m) the observed trend in the annual mean is +0.19 psu/decade (p=0.11, or 89% confidence of a positive trend), with the strongest seasonal

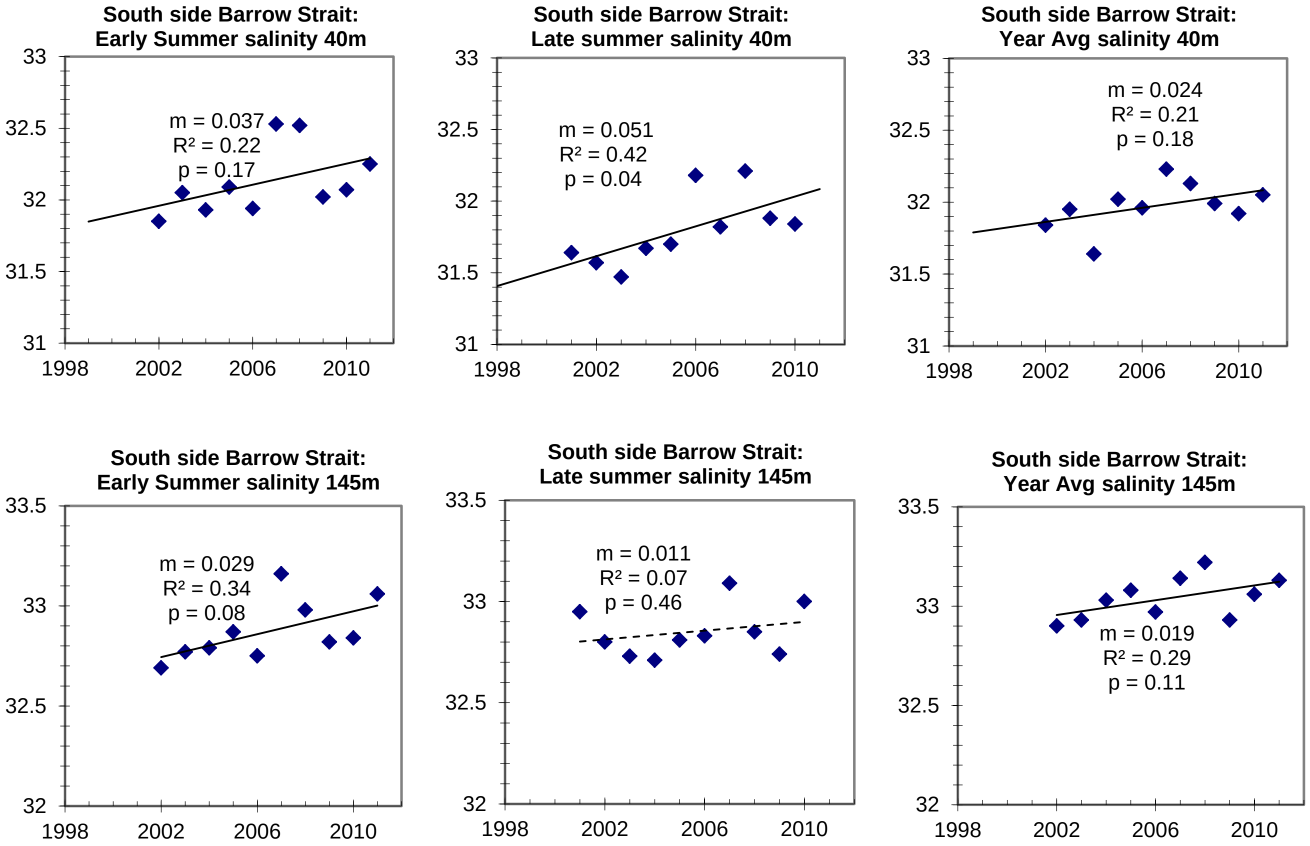

Figure 6. A trend analysis of seasonally averaged salinity at 40 and 145 m depth from the South side of Barrow Strait, for early summer (June 21 to ~ Aug 5) and late summer (~Aug 5 to Sept 21), and for the annual means. Trend line slope (m) units are psu/year. There is better than 80% statistical certainty (p<0.2) that the solid trend lines shown are non-zero.

increase occurring in early summer (+0.29 psu/decade), significant at the 92% confidence level. Only near-bottom do we see a notable trend (with 91% confidence) in temperature (Figure 7); +0.19°/decade in the annual mean, with most of that warming occurring in fall, winter and spring. Since there is a mean eastward flow throughout the year on the South side of the Strait, these observations indicate rising water column salinity, and warming of the deeper layer in water passing through this CAA passage into the western North Atlantic.

On the North side of Barrow Strait, where mean currents are near-zero except in late summer and fall when they are weakly westward, there is a trend of increasing summer salinity at all observed levels (40, 80 and 160m depth) but the trend is significant above the 95% level only at 160m, with the strongest trend (+0.43 psu/decade) in the late summer period (Figure 8). The

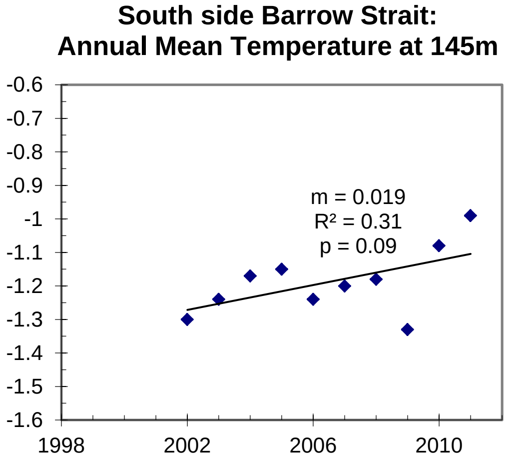

Figure 7. Observed trend in near-bottom water temperature on the South side of Barrow Strait with slope m (°/year). There is a 91% statistical certainty (p = 0.09) the trend is non-zero.

trend at 40m is strong (0.38 psu/decade and 0.60 psu/decade for early and late summer periods respectively) but of lower statistical significance. The trend in late summer water column-averaged salinity is +0.38 psu/decade with p=0.05 (not shown). A statistically significant warming trend of about 0.3°/decade in the mid water column is observed in early summer, late summer (Fig. 8) and in fall (not shown). The trend in the annual mean of the water column-averaged temperature is +0.17°/decade (p =0.09).

Because of the seasonal westward flow, the late summer observations from the North side reflect changes in water from Lancaster Sound, and therefore likely changes in Baffin Bay as well. This is because in late summer and fall, a portion of the southward flowing BIC loops in on the north side of Lancaster Sound, penetrates up into Barrow Strait, and then circulates back out on the south side of the Sound to rejoin the BIC see (Figure 1). Lancaster Sound is an important and productive ecosystem (Milne and Smiley, 1978; Sameoto et al., 1986; Welch et al., 1992). With the observed trends of increasing salinity and temperature presented here being particularly strong in summer which is the biologically active season, there is some likelihood of accompanying impacts on this productive ecosystem.

Part of the water entering Lancaster Sound on the North side mentioned above may have come through Nares Strait. Looking at 6 years of near-bottom measurements (2003-2009),

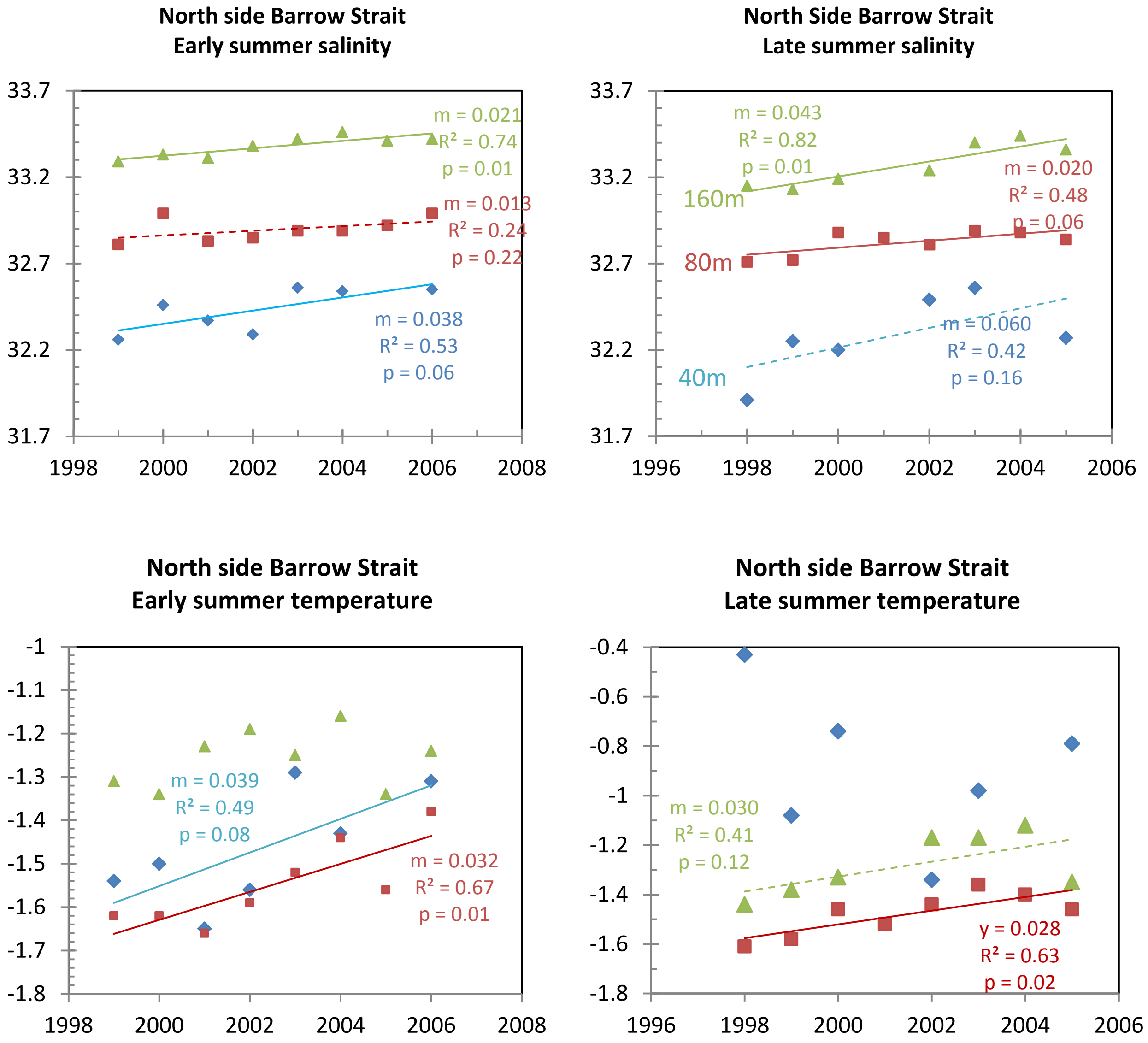

Figure 8. Observed trends in summer T and S on the north side of Barrow Strait from 8 years of mooring data at 40 m (blue),80 m (red) and 160 m (green). Early summer is from June 21 to ~Aug 5. Late summer is from ~Aug 5 to Sept 21. Where the trend lines are solid there is at least a 90% certainty the trends are non-zero The slope (m) of the trend line is in °/year for temperature, and psu/year for salinity.

Munchow et al. (2011) have identified a mean warming of +0.023 ± 0.015 °C/year in Nares Strait (95% confidence), but they do not observe any trend in salinity.

There are also observed trends in ice cover in Barrow Strait. The presence of ice can be determined from the bottom-track feature of the acoustic Doppler current profilers (ADCPs) that were used in the monitoring program to give dates for freeze-up and break-up. Figure 9 demonstrates that at higher than 90% confidence, there is a trend towards an earlier freeze-up on

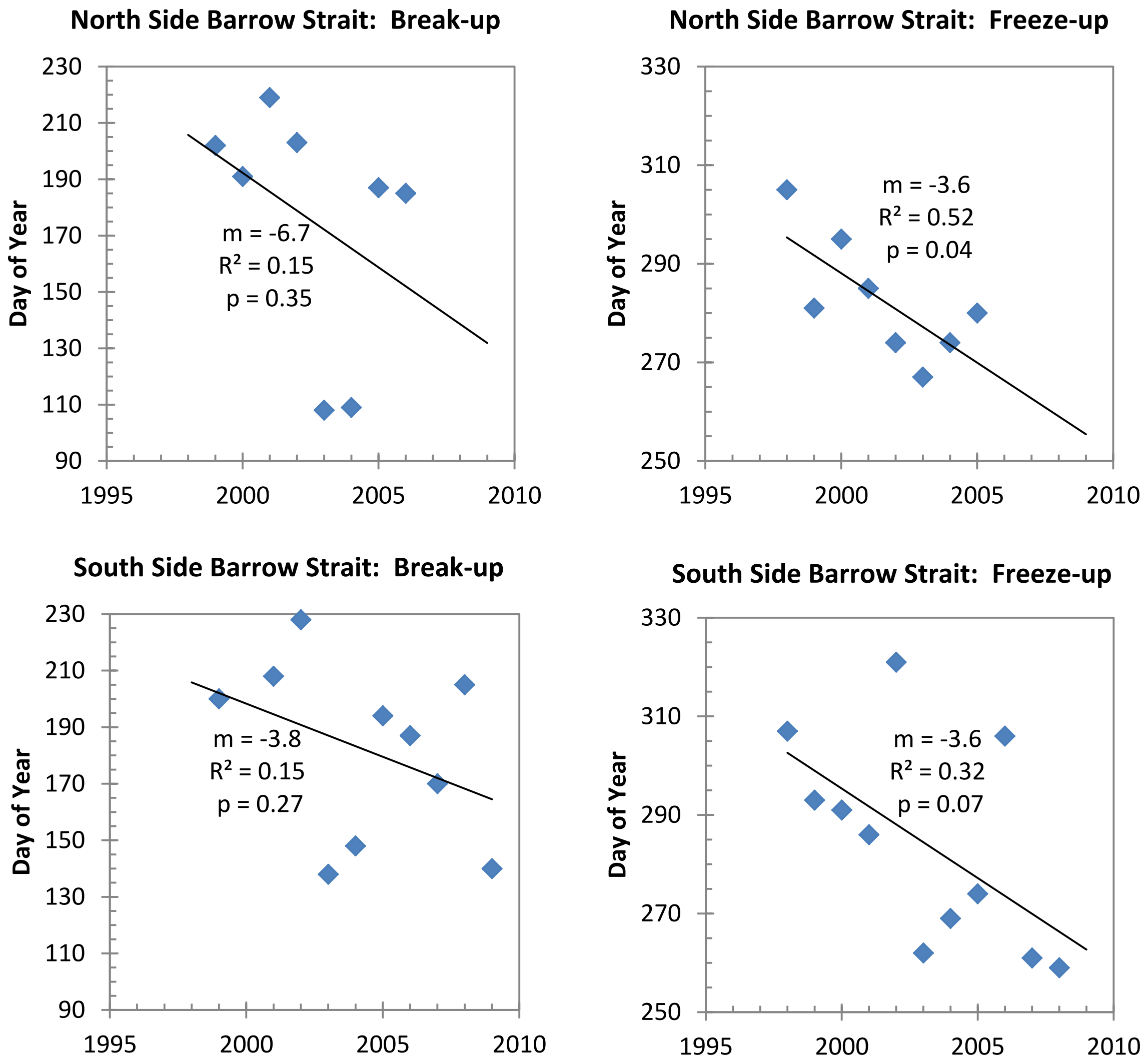

Figure 9. Trends in freeze-up and break-up date from ADCPs moored on both sides of Barrow Strait, with slope, m in days/year. The observed trends towards earlier freeze-up are statistically significant to better than 90%, but the trends toward earlierbreak-up are not as statistically reliable.

both sides of the strait of about 4 days per year. While there is a great deal of scatter in break-up dates, there is also a trend (with poor statistical reliability) towards an earlier break-up at both locations, suggesting an on-going shift of the ice free period to earlier in the year.

Ice Profiling Sonar data from the Barrow Strait monitoring program presently being analyzed will provide information on variability in ice thickness during the field program in the near future.

The trends presented here provide insight into recent changes occurring in Barrow Strait, an important Baffin Bay input. But the decade long records are short in the context of being able to attribute such trends to climate change or natural variability. Predicting future change through extrapolation of such results cannot be done with any confidence.

3.2 Arctic Ocean freshwater input from Fram Strait

The other major pathway for the exit of freshwater from the Arctic Ocean is Fram Strait, a 500 km wide passage between the northeast tip of Greenland and Spitsbergen. Here, the East Greenland Current (EGC) carries freshwater in solid and liquid form southward from the Arctic Ocean, along the eastern coast of Greenland to Cape Farewell. Somewhat constrained to the Greenland continental margin this freshwater then flows around the southern tip of Greenland and northward along the West Greenland Shelf. On this northward journey there is entrainment into the Labrador Sea and Davis Strait, but a portion continues northward to the top of Baffin Bay as part of a cyclonic circulation, to join the southward CAA outflow along the eastern Canadian coast.

Ice

Ice accounts for over half of the Arctic freshwater export through Fram Strait. Spreen et al, (2009) have estimated the volume export from satellite data for the period 2003 to 2008. Their 5 year average is 83 mSv (with the range in computed monthly means of 35 to 160 mSv) This estimate is similar to earlier estimates by Vinje et al. (1998) of 90 mSv, Kwok et al. (2004) of 70 mSv, and also those of Widell et al. (2003) at 76mSv, and Aagard and Carmack (1989) at 88 mSv. A strong seasonal cycle reveals a peak ice transport in March (~110 mSv) and a minimum in August (~ 35 mSv) (figure 3a, Spreen et al., 2009). Spreen et al. (2009) see no significant trend in ice fluxes when they compared observations in the 2000s with those in the 1990s.

Using a century of historical sea level data and a coupled circulation model, Jung and Hilmer (2001) found no significant wintertime link between Fram Strait ice export and the NAO on inter-annual to inter-decadal time scales, although they note a recent correlation over the last 2 decades. Indeed Kwok et al. (2004) show this recent correlation to be high (r^2=0.62) over the 1978-2002 period when years of extremely low NAO are excluded from the calculation.

Liquid

de Steur et al. (2009) provide estimates for the liquid component of freshwater export through Fram Strait based on a decade of measurements in the EGC and also compute transports on the shelf using hydrographic data and a computer model. Their annual mean from 10 years of measurements in the EGC is 33.6 ± 12.5 mSv (using a 34.8 salinity reference), and they estimate another 25.6 ±11.3 mSv on the shelf, for a total southward fresh water flux of 59 ± 24mSv at ~79°N. Transports on the shelf and in the EGC appear to be out of phase at least on an inter-annual time scale, resulting in less variability in the total liquid transport than is seen in the individual components. Peak in the freshwater seasonal cycle in the EGC and on the shelf both occur in fall, while minimum transports are in summer.

Summing the annual mean values for ice (Spreen et al., 2009) and liquid (de Steur et al., 2009) transports, we get an overall average freshwater flux through Fram Strait of 142 mSv.

The transit from Fram Strait to the Northwest Atlantic

Hopkins (1991) claims that the freshwater exiting through Fram Strait remains geostrophically constrained to the Greenland Continental Margin as it moves southward. Estimates of the quantity of liquid freshwater diverted into the Nordic Seas are indeed relatively low. Jonsson and Briem (2003) used hydrography and direct measurements to estimate 5 mSv is removed by the East Icelandic Current, and Jonsson (2003) gives 10 mSv based on historical literature for the quantity diverted to the Jan Mayen Current, leaving ¾ of the liquid freshwater passing through Fram Strait to pass through Denmark Strait and into the North Atlantic.

The fate of Fram Strait ice export is not as well understood. Vinje et al. (2002) give sea ice melt rates of from .06 m/month in January to 0.72 m/month in October as ice moves southward in the EGC. Dodd et al. (2009) use tracer analysis and referenced geostrophic shear profiles to estimate a net melting of sea ice that adds 10 mSv of freshwater to the EGC between Fram Strait and Denmark Strait, but they conclude that the bulk of the ice passes into the Nordic Seas, or onto the Greenland Shelf. This is in contrast to the freshwater budget of Dickson et al (2007), which has the majority of the ice melting within the EGC, and then being exported into the North Atlantic. Dodd et al. (2009) did their study in summer, and they acknowledge this misses the significant sea ice export through Denmark Strait in winter, but the two estimates of EGC freshwater export are very different (151 mSv for Dickson et al, 43-60 mSv for Dodd et al).

Sutherland and Pickard (2008) completed high-resolution hydrographic and velocity transects across the southeast Greenland shelf at Denmark Strait (68°) and Cape Farewell (60°). Their analysis indicates that the freshwater transport across the combined East Greenland Coastal Current (EGCC) and EGC increases from 59 mSv to 96 mSv over this 1200 km distance. They attribute this increase to additions from sea ice melt water, iceberg melt water, Greenland melt water runoff, and precipitation. Aagaard and Carmack (1989) estimate the sea ice flux through Denmark Strait to be 18 mSv which is in good agreement with Kwok and Rothrock's (1999) estimate of 19 mSv from satellite imagery. Assuming all of this ice melts by the time it reaches Cape Farewell (true in summer only) then half of Sutherland and Pickard's (2008) observed increase is accounted for. Remaining identified sources are 4 mSv for Greenland runoff, 2 mSv for iceberg melt, and 2.5 mSv for precipitation.

In summary, multi-year averages of freshwater transport through Fram Strait (79°N) are 83 mSv for ice and 59 mSv for liquid for a total transport of about 140 mSv. As this water moves southward along the coast, about ¼ of the liquid is diverted into the Nordic Seas as well as a poorly defined portion of the sea ice. The sea ice staying in the EGC and EGCC undergoes significant melting by the time it reaches Denmark Strait (68°N). Here about 59 mSv of liquid and 19 mSv of solid freshwater remain in the coastal flows. Continuing southward, Greenland runoff, iceberg melt and precipitation contribute so that roughly 96 mSv of freshwater (combined liquid and solid) rounds Cape Farewell to enter the western North Atlantic. This provides a crude estimate, from sparse data and with significant uncertainties particularly in the ice budget. This bulk value also ignores the seasonality in the fluxes. The published data are also too sparse to accurately assess any trends in the fluxes, which is unfortunate since changes in the EGCC and EGC freshwater fluxes will have impacts in Baffin Bay, Davis Strait and the Labrador Sea.

On entering the western side of the Atlantic via the EGCC and the EGC, this imported freshwater is carried northward along the western shelf and slope of Greenland by the WGC. (The WGC originates at Cape Farewell where the EGC is joined by the warm, saline Irminger Current (Clarke, 1984) to form this important circulation feature in the Northwest Atlantic.) During the 1100 km transit to Davis Strait, some of this freshwater being transported along the slope is lost to the surface waters of the Labrador Sea, including a significant portion that swings westward with Irminger Sea water at the top of the Labrador Sea. The remainder continues northward through Davis Strait as an extension of the WGC. Cuny et al. (2005) report a northward freshwater transport of 22 mSv on the slope from their mooring measurements at Davis Strait, and another 38 mSv on the shelf based on hydrographic data, but the latter is likely an overestimate since they include a barotropic component that is based on their current measurements over the slope where currents are higher compared to those on the shelf. Curry et al. (2011) compute a northward shelf transport of only 15 mSv from a year of moored measurements on the shelf. Using their shelf estimate with the slope transport of Cuny et al. (2005), a rough estimate of the mean northward freshwater transport on the west Greenland slope and shelf at Davis Strait is ~37 mSv based on the very limited data available. This is about 40% of the freshwater import into the western North Atlantic at Cape Farewell.

3.3 Greenland Ice Sheet Freshwater Input

A rapidly growing freshwater input into the North Atlantic is runoff from the Greenland ice sheet. Rignot et al. (2011) have reconciled estimates from the 2 principal loss detection methods (mass budget method and the gravity method) to provide consistent estimates of rate of ice sheet loss. They calculate the loss in 2010 at 350 Gt/year or 12 mSv. Based on an 18 year record, they calculate an acceleration of the loss rate from 1992 (when mass change was slightly positive) to 2010 of 22 ± 1 $\mathrm{Gt/yr^2}$ (0.76 mSv/yr). Bamber et al. (2012) used a regional climate model to reconstruct past ice sheet surface mass balance. Their result shows a relatively stable ice sheet with constant freshwater discharge from 1958-1992, and the discharge about equally split between runoff and solid ice discharge. But after 1992, they too show an accelerating discharge rate (16.9 $\mathrm{km^3y^{-2}}$ ± 1.8, or 0.54 mSv/year) that is close to that of Rignot et al. (2011). Their result also indicates that 80% of the total Greenland discharge enters the ocean on the western and south-eastern coasts (based on 1962-1990 averages), and that between 1992 and 2010 the direct discharge along the shores of Baffin Bay, the Labrador Sea and Irminger Sea has increased by 22%, 48% and 49% respectively.

If we assume the observed increase in glacier loss rate of Rignot et al. (2011) remains constant (a strong assumption considering the acceleration rate is based on only 18 years of data), Greenland meteoric water input will more than triple to 42 mSv by 2050. If ¼ of this water enters directly into Baffin Bay (the portion calculated for the 1961-1990 period in Bamber et al. (2012)), and half of the remainder enters from the south through Davis Strait having been transported by the coastal currents (and allowing for some loss of freshwater offshore during the transit), then meteoric water input into Baffin Bay will grow from 7.5 mSv (2010) to 26 mSv by 2050.

Since it is difficult to predict the magnitude and impact of global warming related changes in precipitation, albedo and cloud cover on melt rates, uncertainty in future mass change rates are significant (Rignot, 2011). Furthermore, their 18 year record is not long considering the potential influence that decadal-scale variations in the North Atlantic Oscillation may have on the Greenland ice sheet melt rate. But Hanna et al. (2008) attribute the strong increase since 1990 in summer temperatures along the southern Greenland coast and the accompanying accelerated ice sheet mass loss, to global warming rather than multi-decadal natural variability. They show that southern Greenland temperatures were significantly negatively correlated to the NAO from 1960 to 1990, but not thereafter. Since 1990, southern Greenland air temperature has been significantly correlated with general Northern Hemispheric and global warming. With the expected continuation of anthropogenic warming of both the atmosphere and the ocean, there is little to suggest that glacial melt will not continue to accelerate over the longer term.

Although Canadian glaciers and ice caps contain only 10% of the Greenland ice sheet volume, the extreme melting Sharpe et al. (2011) attribute to higher summer air temperatures is also accelerating, and will contribute to increased freshwater discharge into Baffin Bay.

3.4 Impacts of Greenland Ice Sheet Freshwater Input

Because of the cyclonic circulation in Baffin Bay/Davis Strait, the increased fresh water input along the coast of Greenland will be carried along the coasts by the WGC and BIC, and remain relatively confined to the shelves and slopes. We can make a crude estimation of the freshening of the BIC if we speculate that the glacier loss acceleration rate of Rignot et al.,(2011) is applicable out to 2050 and the resulting increased freshwater input of about 22 mSv (19 mSv from Greenland plus 3 mSv from Baffin/Ellesmere Islands) is confined to the western coast in a 150m deep by 150 km wide current. (We also assume the CAA freshwater inputs remain constant for this calculation). Assuming a volume transport in this current of 2 Sv (thus a mean speed of 9 cm/s) at Davis Strait , this 150m layer would be freshened by about 0.4 psu by 2050 (33psu × 22mSv/2 Sv, where 33 is the mean salinity of the 150m layer today). As this water moves southward and is entrained by the Labrador Current it will be diluted by mixing with deeper and adjacent water. The extent to which it will impact conditions along the Labrador and Newfoundland shelves and banks is uncertain.

4.0 TRANSPORTS THROUGH DAVIS STRAIT

Freshwater fluxes through all the passages of the CAA pass through Davis Strait to get to the North Atlantic. Much of the meteoric water from melting glacial ice in Greenland and the Canadian Arctic will also be exported through Davis Strait. This makes Davis Strait a strategic location for monitoring the exchange between the Arctic and North Atlantic Oceans. With a minimum width of over 300 km, long term monitoring with sufficient instrumentation to resolve transports is a challenge, but results from a mooring array maintained since 2004 across Davis Strait are now becoming available. Currie et al. (2011) calculate an annual mean southward freshwater transport of 116 ± 41 mSv from the first year of this mooring time series (the location of the mooring array is shown in Figure 1). As observed in Barrow Strait, there is high seasonal variability in the freshwater transport. Their mean freshwater transport is close to the previous estimates of Tang et al. (2004) of ~120 mSv who used mooring data collected in 1987-1990 (Ross, 1992), and of Cuny et al. (2005): 92±34 mSv. This value is also consistent with the 100 mSv estimate of the export through the CAA straits reviewed above. We expect that the net southward transport through Davis Strait will be the sum of the CAA import plus about 4 mSv for glacial run-off. (The northward flowing freshwater entering on the eastern side of Davis Strait via the WGC (described at the end of Section 3.2) is balanced by its exit on the western side in the BIC.)

Until results from the 8 year time series of mooring data at Davis Strait are published, little can be said about inter-annual variability, or whether there are short term trends in the Davis Strait measurements. But there have been numerical modeling studies to investigate the freshwater fluxes through Davis Strait. For instance, Lique et al. (2009) discussed the freshwater flux variability during 1965-2002 using the DRAKKAR eddy admitting global ocean/sea-ice model and reported a mean flux is 122 mSv in liquid and about 17 mSv in solid (sea ice). This result is consistent with the measurement-based estimates discussed above. Using the same model with a state-of-the-art data assimilation scheme implemented, Zou et al. (2011) simulated freshwater transports that indicated a downward trend in the sum of the freshwater transports through Davis Strait and Fury and Hecla Strait between 1997-2004 in their 1987-2004 simulation period.

5.0 TEMPERATURE AND SALINITY IN BAFFIN BAY/DAVIS STRAIT

Temperature and salinity used in this analysis is the monthly gridded climatology dataset, which is derived from field observations taken between 1910 and 2009 using the optimal interpolation algorithm of Tang (2007). Figure 10 shows depth-averaged temperature and salinity in the upper 100 m. Because of the paucity of observations in the ice season, only data in ice-free or light-ice months (August-October) are shown. The signature of the WGC carrying warm, salty Irminger Sea water into the southeast of Baffin Bay can be seen, as well as a hint of the fresher water against the Greenland coast originating from the EGCC. In the northwest of Baffin Bay, the signature of cold and fresh Arctic water flowing southward along the eastern coast of Baffin

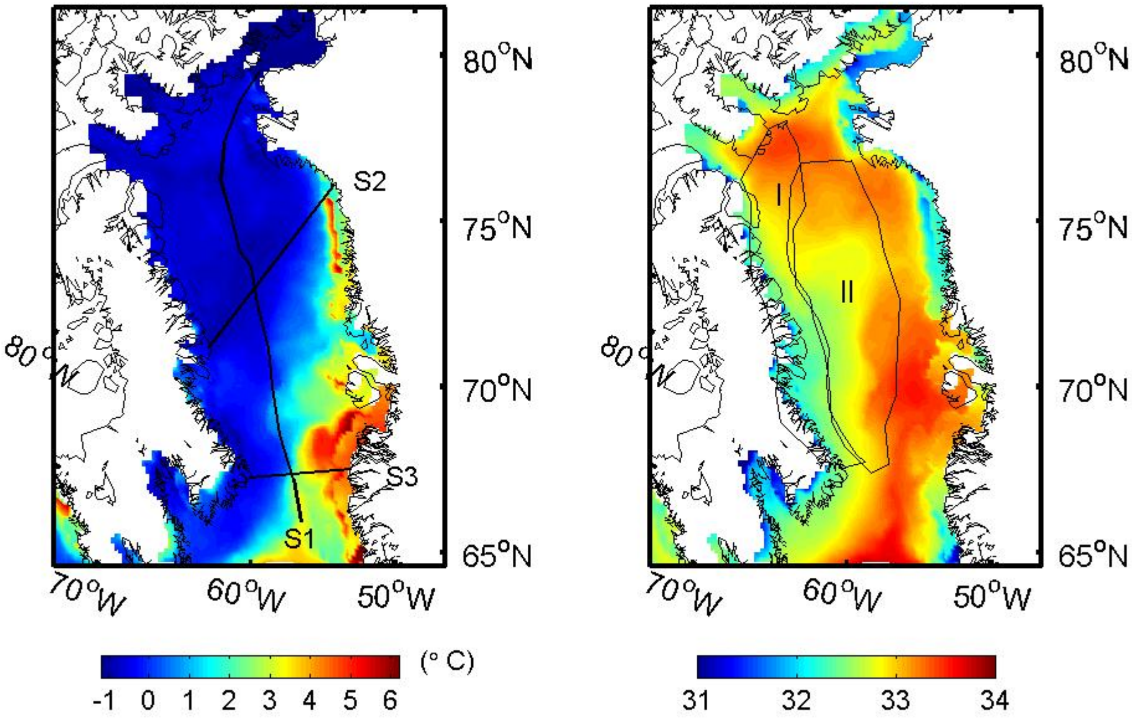

Figure 10. Summer (August to October) temperature (left) and salinity (right) averaged in upper 100 m. The black lines in the left panel are the locations of vertical sections (S1, S2, and S3) used in Fig. 11-13. The areas in the right panel indicate the domains for trends analysis. I represents the Baffin Island Shelf and II represents Baffin Basin.

Island can clearly be seen. The temperature in the northwest region is 4°C lower than that in the southeast region. Salinity in the central Bay is higher than that in the coastal waters.

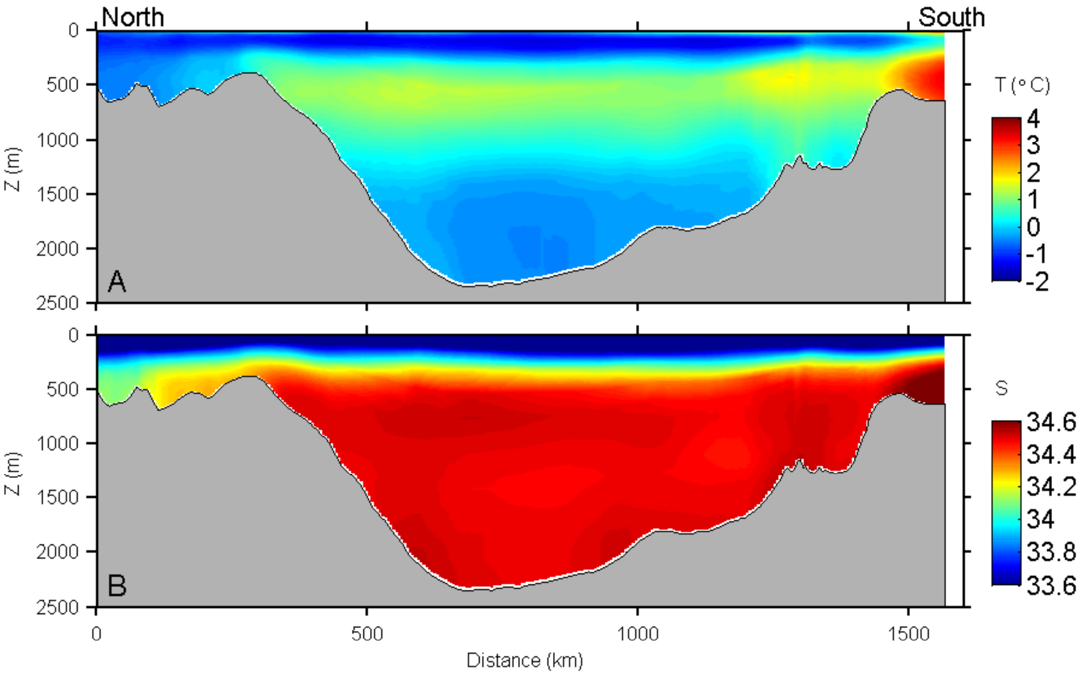

Figure 11. Vertical distributions of temperature (A) and Salinity (B) along Section 1.

Vertical distributions of temperature and salinity are shown along the three transects (S1, S2 and S2) identified in Fig. 10. S1 is a north-south cross-section down the center of Baffin Bay, and S2 and S3 are east-west sections across central Baffin Bay and Davis Strait, respectively. Section S1 (Fig. 11) covers about 1550 km from the north end of Baffin Bay to the north edge of the Labrador Sea. Over the deeper part of the section (350~1400 km interval), the temperature structure reveals three layers; a cold surface layer (<200 m), a warm intermediate layer (200~1000 m) and a deep layer (>1000 m) with a temperature between those of the above two. Characteristic temperatures for the three layers, from surface to bottom, are -1, 1 and 0°C, respectively. The horizontal and vertical distribution of salinity matches much of the pattern seen in the temperature. In the upper layer, lower salinity correlates closely with lower temperature, but there is not as clear a salinity difference below 200m to differentiate between an intermediate and deep layer as there is in the temperature.

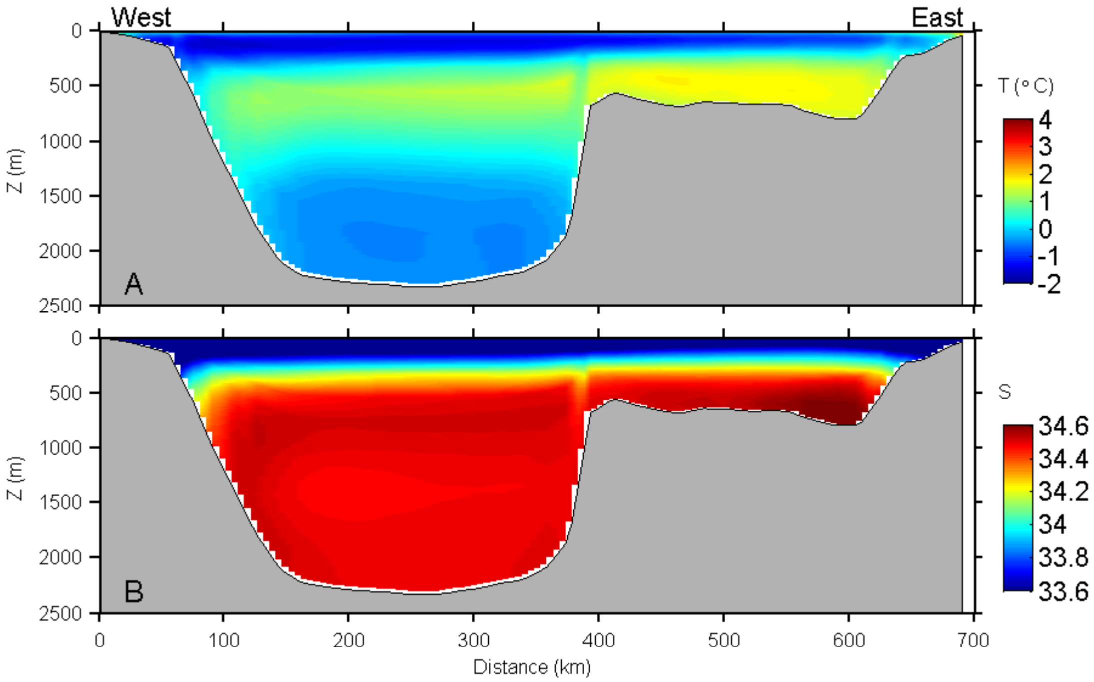

Figure 12. Vertical distributions of Temperature (A) and Salinity (B) along section S2.

Along section S2, we again see a three-layer structure in Baffin Basin (80-400 km) which shows up in the salinity as well here (Fig. 12). Over the West Greenland Shelf (400~650 km) there is a two-layer structure. The deeper shelf water is clearly warmer and saltier than that in the upper 200m. Overall, the water on the West Greenland Shelf is warmer and saltier than that in the deep Baffin Bay Basin, except right against the coast (650~700 km of Fig 12) where there is a hint of the cold, fresh Arctic water that is the continuation of the EGCC.

Strong spatial features in temperature across Davis Strait (section S3) are evident in Figure 13. Colder, fresher water is found along the Baffin Island coast, whereas warmer, saltier water is found off West Greenland. The east-west gradient in the temperature (salinity) reaches 5.0 °C (1.0) in the surface layer (< 200 m), and about 1~2 °C (0.5) below 200 m. The warmer and saltier water on the West Greenland Slope with the core at 400 m depth is of Irminger Sea origin.

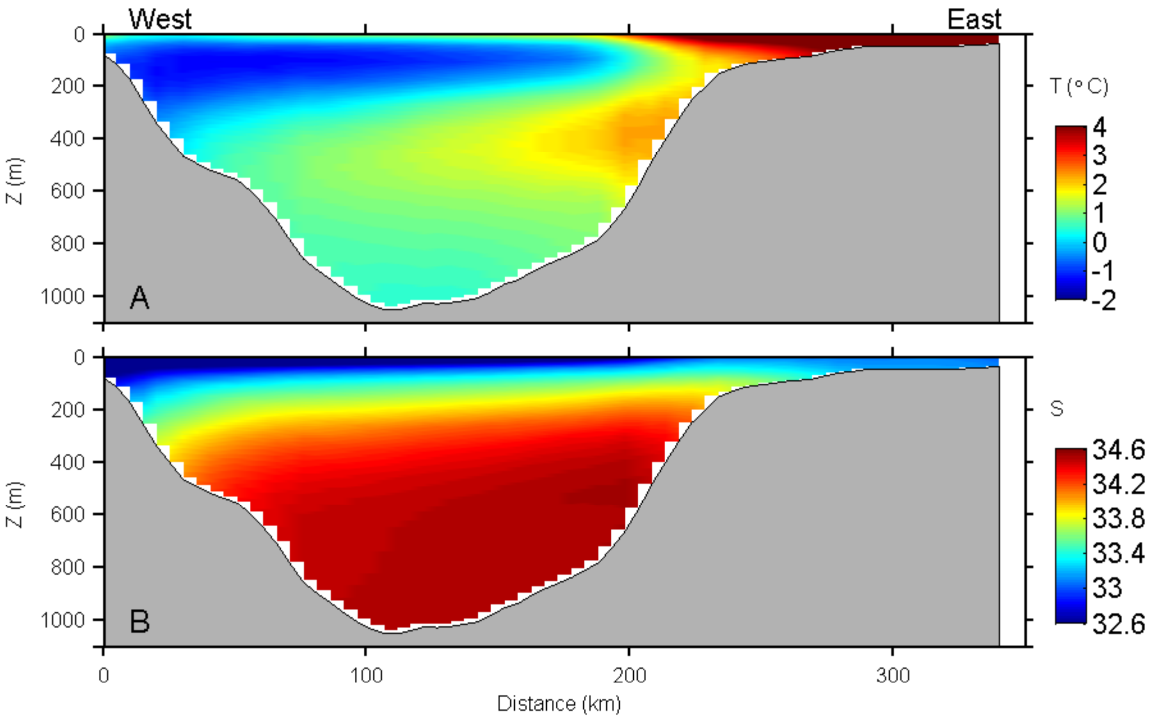

Figure 13. Vertical distributions of temperature (A) and Salinity (B) along section S3.

6.0 TRENDS IN OCEAN TEMPERATURE AND SALINITY

Using field observational temperature and salinity data archived at Bedford Institute of Oceanography, a preliminary analysis of the trends of temperature and salinity in Baffin Bay and Davis Strait region is possible. Considering the temporal variability of ice coverage, only the data in the ice free period (August to October) are analyzed. In this report, the trend analysis focuses on the following two regions. One is the Baffin Island Shelf and the other is the Baffin Basin. The definitions of the two regions are plotted in Figure 10. As described earlier, the former is the pathway of the cold and fresh water from the CAA. The latter is impacted by the warm and salty Irminger Sea water. For a given region and a specific year, August, September and October monthly mean temperature and salinity values are averaged, to represent the station mean for the year. Only when more than 5 station values are available in a year are the data used in the trend estimation.

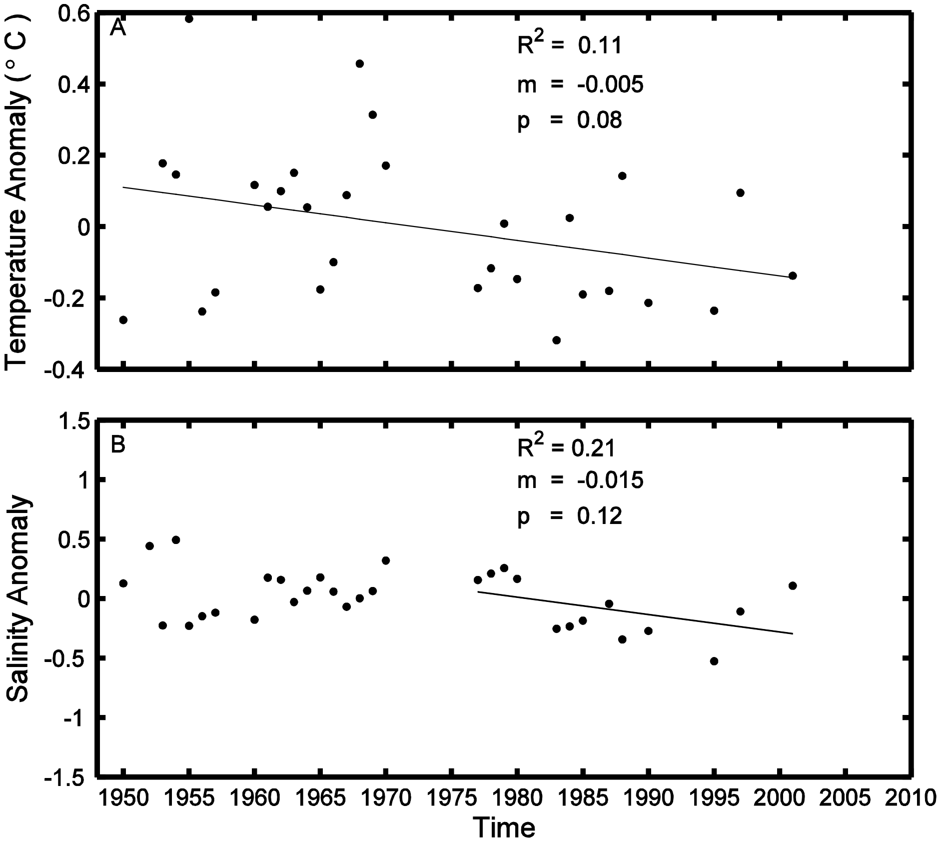

Figure 14. Anomalies of annual mean temperature (A) and salinity (B) in the upper layer (50-200 m) over Baffin Island Shelf (See the domain definition in Fig. 10). The trend lines (with slope m) for temperature (°/year) and salinity (psu/year) are statistically significant at about the 90% level.

A time series of the anomalies of temperature and salinity in the 50 to 200m interval over the Baffin Island Shelf (region I) is plotted in Figure 14. There is strong inter-annual variation in both temperature and salinity. Only a weak trend in temperature is evident. Over the 52 year salinity record there is a significant trend (p= 0.04) towards lower salinity of -0.06 psu/decade which is similar to that of Zweng and Munchow (2006), who computed a value of -0.086±0.039 psu/decade over this depth range when computed with data from 1916-2003. Most of the observed salinity decrease in Fig. 14b occurred from 1978 until 2001 (the end of the record). Over these latest years the trend is -0.15 psu/decade (significant at the 88% confidence level).

Trends in temperature and salinity in the 0-50 m layer are also analyzed (Fig. 15). No significant trend is observed in either T or S. The differences in trends for the 0-50m layer compared to the 50~200 m layer points to the impact of layer choice in such an exercise. If the layer choice is 0-200m, the trend in salinity observed in the 50-200m layer gets masked by the inclusion of the highly scattered surface layer data.

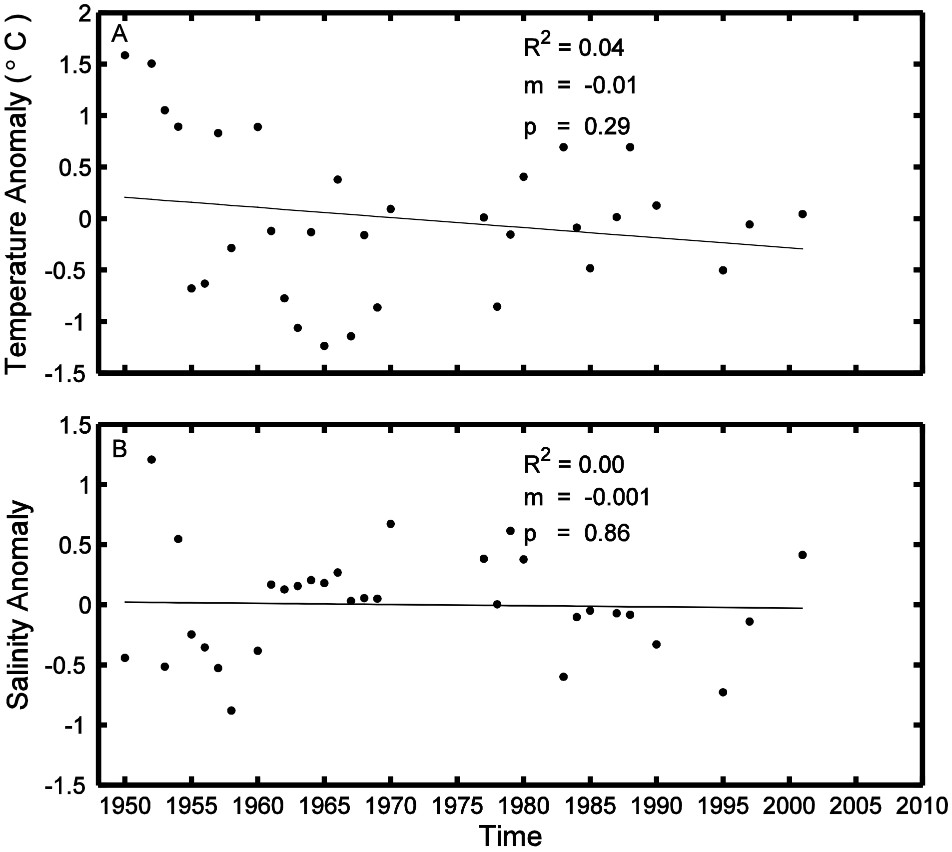

Figure 15. Anomalies of annual mean temperature (A) and salinity (B) in the surface layer (0 - 50 m) over Baffin Island Shelf (See the domain definition in Fig. 10). The trend lines shown are not statistically reliable.

The time series of the anomalies of salinity and temperature computed over the depth range of 600~800 m in Baffin Basin (Region II) are shown in Figure 16. This depth interval is in the middle of the intermediate layer defined earlier. No significant trend is observed in salinity, but a strongly statistically significant trend in temperature of +0.13 °C/decade is observed in the 45 year long time series. This warming trend is also consistent with the estimation of Zweng and

Munchow (2006), who found that the intermediate water is warming at a rate of 0.11±0.06 °C/decade.

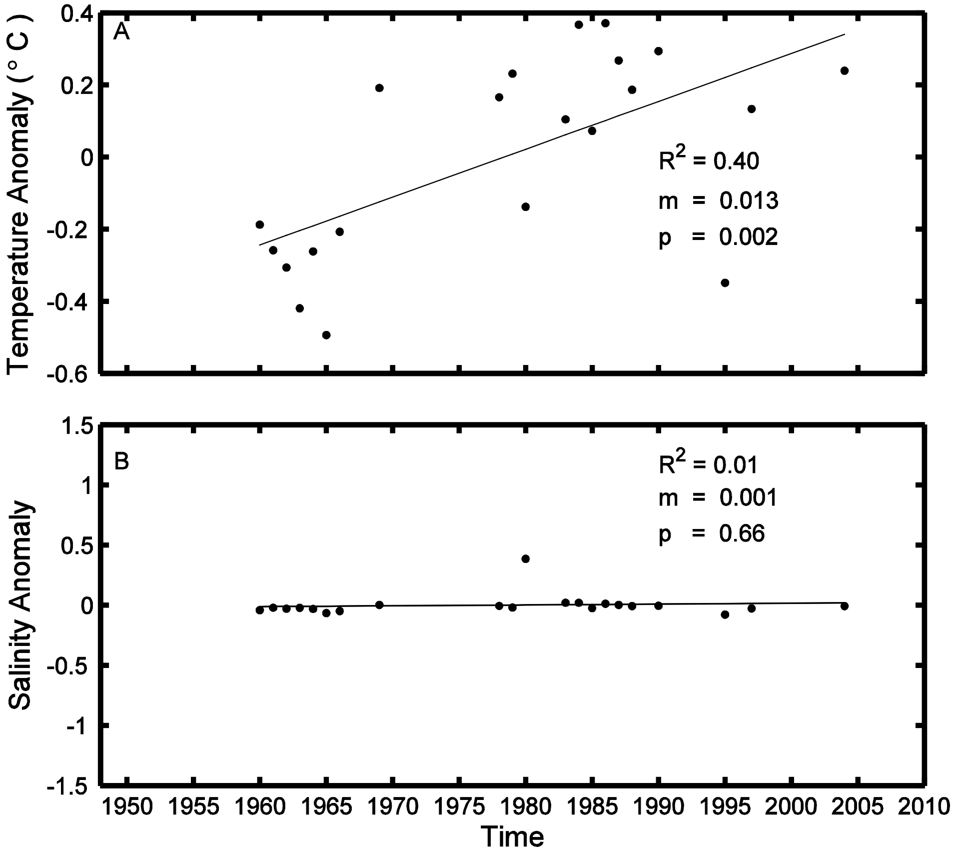

Figure 16. Anomalies of annual mean temperature (A) and salinity (B) in the intermediate layer (600-800 m) of Baffin Basin. The displayed trend in the temperature anomaly is of very high statistical significance. Slope, m of the trend line is in °/year for temperature,and psu/year for salinity.

Trends in two upper layers in Baffin Basin were calculated as well. The time series of the anomalies of salinity and temperature computed over the depth range of 0-50 m in Baffin Basin are shown in Figure 17. There is large inter-annual variability in both the temperature and salinity data. A cooling trend of -0.16 °/decade is significant at the 94% confidence level. There is no reliable trend information identified for salinity. Data from the 50-200 m layer were also analysed but showed no significant trends in the highly scattered data.

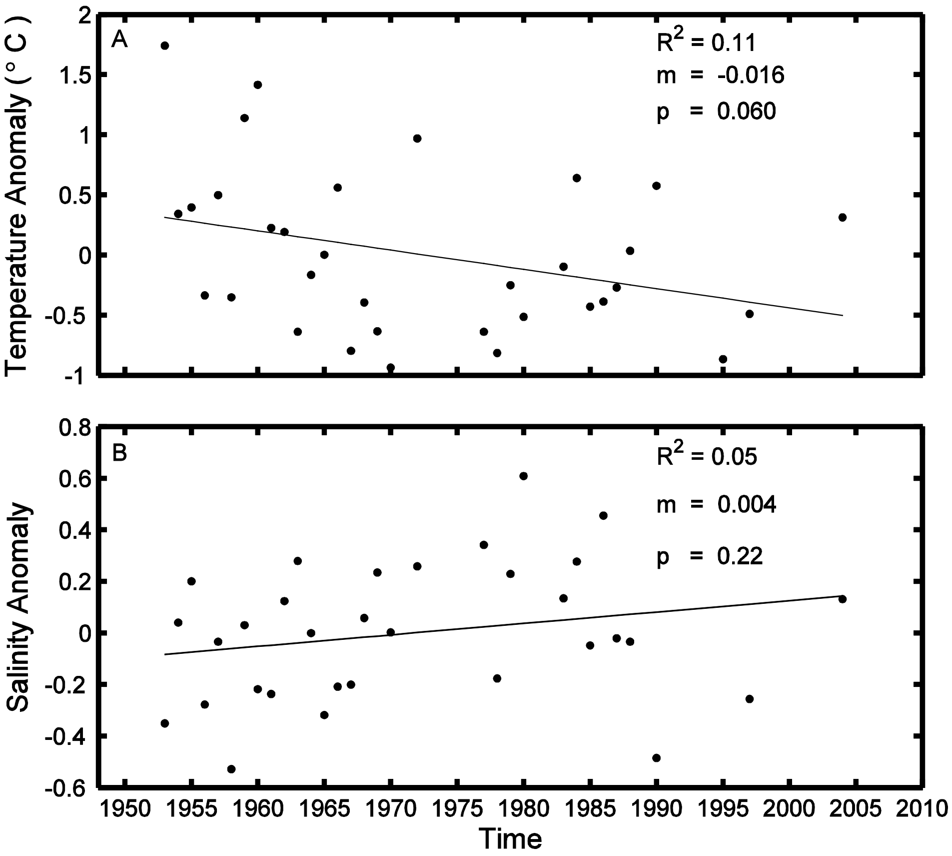

Figure 17. Anomalies of annual mean temperature (A) and salinity (B) in the surface layer (0-50m) of Baffin Basin. Slope, m of the trend line is in °/year for temperature,and psu/year for salinity

In summary, over the Baffin Island shelf from 1950 to 2003, there has been freshening in the near-surface layer (50~200 m) of -0.06 psu/decade. The strongest freshening occurred at the end of the record (from 1978 to 2003). Although not as statistically reliable (p=0.12 or 88% confidence) the trend over the last 2 decades of the record is -0.15 psu/decade. In the middle of the intermediate layer (600-800 m) in Baffin Basin a highly significant warming trend of 0.13 °C/decade is observed over the 1960-2005 period.

7.0 TRENDS IN AIR TEMPERATURE, WIND SPEED AND PRECIPITATION

Since the atmosphere plays an important role in heat exchange with the ocean, in influencing sea ice formation and decay, in forcing through wind, and in delivering freshwater through precipitation, identifying atmospheric trends is important in projecting the future ocean environment.

The atmospheric data used in the following trend analysis are from Environment Canada Climate Trends and Variations dataset AHCCD (Adjusted and Homogenized Canadian Climate Data, http://ec.gc.ca/dccha-ahccd/default.asp?lang=En&n=B1F8423A-1).

Sixty year records of air temperature from 3 stations along the eastern coastline of the Canadian Archipelago (Vincent et al., 2002) are shown in Figure 18. From north to south the stations are Alert (82.50 ºN, 62.33 ºW) at the extreme northern tip of Ellesmere Island, Pond Inlet (72.70 ºN, 77.97 ºW) in central Baffin Bay and Clyde (70.48 ºN, 68.52 ºW) in southern Baffin Bay (1600 km south of Alert). The air temperature records reflect 2 distinct periods. Over the period 1950-1999, there is the suggestion of some slight warming but the signal is not statistically significant above the observed inter-annual variability. While not reliable statistically, trends in mean temperature of +0.1, +0.5 and +0.1 ºC/decade are computed for Alert, Pond Inlet and Clyde respectively over this earlier period. In recent years, the data reveal a sharp increase in temperature at all three stations. From 1999-2011 trends of +2.9, +2.2 and +1.6 ºC/decade are computed. Note that the warming is greatest at the northern station and weakest at the southern station, but dramatic and significant at all 3 stations.

Compared to the western side, the temporal variability of air temperature over the eastern side of Baffin Bay has received more attention since it is associated with the melting of the Greenland ice sheet, which has become a common concern in future climate projections with sea level rise (Chylek et al., 2006; Kobashi et al., 2010). Using a combination of meteorological station records (8 stations along the western coast of Greenland) and regional climate models, Box et al. (2009) built continuous 168-year (1840-2007) ice sheet near-surface air temperatures. They found periods of warming; 1885-1919, 1862-73, 1919-32, and 1994-2007, and two cooling periods; 1932-46 and 1955-82. Warming from the 1919-32 to the 1994-2007 periods was strongest along western Greenland in autumn, but strongest along southern Greenland in winter.

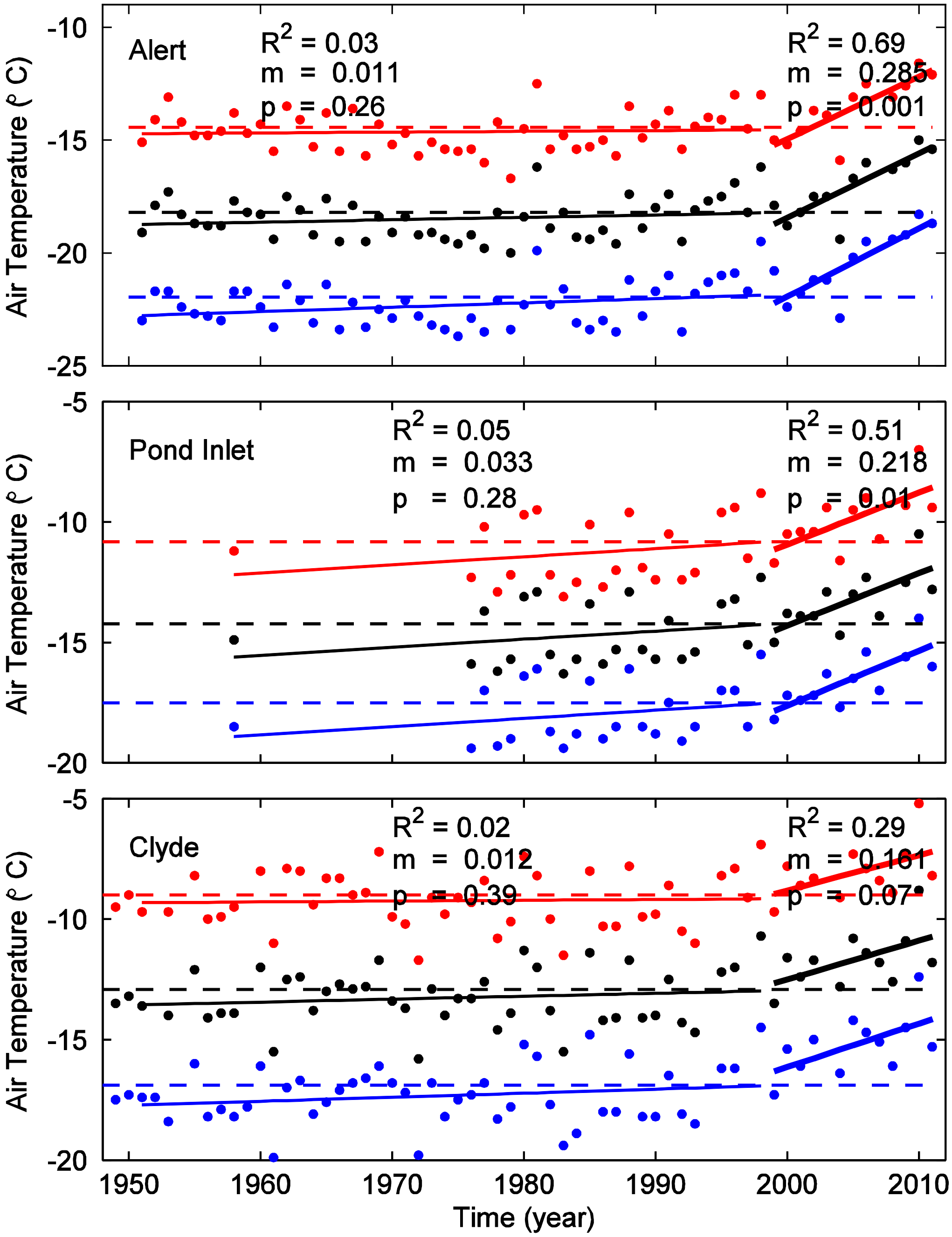

Figure 18. Time series of air temperature at Alert (top), Pond Inlet (middle) and Clyde (bottom). The colors red, blue and black represent the annual maximum, minimum and averaged air temperature, respectively. Dots, dash lines and solid lines indicate raw data, raw data mean and trend lines (m in °/year). R^2 is calculated from mean value analysis. The recent (1998-2010) warming trends shown are statistically significant with better than 90% confidence.

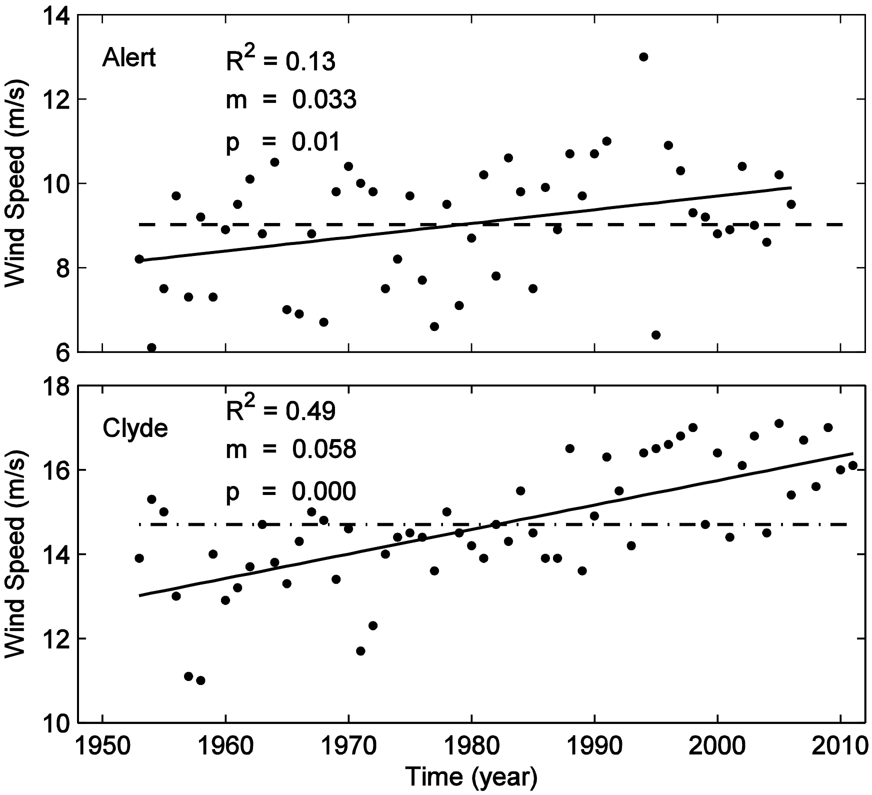

Figure 19. Time series of annual mean wind speed at Alert (upper) and Clyde (lower). Dots, dash lines and solid lines indicate raw data, raw data mean and trend lines.There is strong statistical certainty these are positive trends at both stations.

Fifty-eight year records of annual mean wind speed at Alert and Clyde (Wan et al., 2010) are plotted in Figure 19. There is a positive and statistically significant trend in wind speed at both stations over the 1954-2011 period shown, although there is strong inter-annual variability particularly at Alert. At Alert this trend is +0.33 $m{\cdot}s^{-1}$/decade while at Clyde the trend in annual mean wind speed over the last 58 years is +0.58 $m{\cdot}s^{-1}$/decade.

Time series of annual mean precipitation at Alert and Clyde (Mekis and Vincent, 2011) are plotted in Figure 20. Strong inter-annual variability can be found at both stations but at Alert there is a statistically significant trend ($p<0.05$) of about +10 mm/decade over the 60 year record.

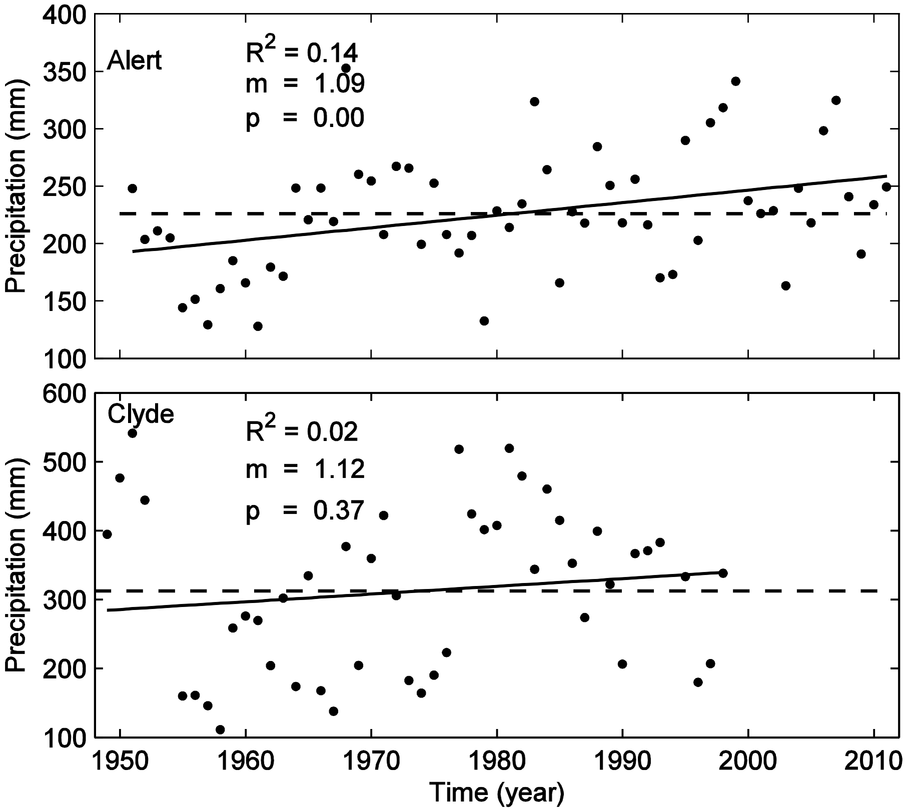

Figure 20. Time series of annual mean total precipitation at Alert (upper) and Clyde (lower). Dots, dash lines and solid lines indicate raw data, raw data mean and trend lines. The trend at Alert is statistically significant but that at Clyde is not.

8.0 TRENDS IN SEA ICE

Another important component of the physical environment of Baffin Bay and Davis Strait is sea ice, which is strongly related to air temperature. The reader is referred to Peterson and Pettipas (2013) for a complete description of sea ice and iceberg trends. Their analyses demonstrate a decline in sea ice area over the last 2 decades in all seasons, with the greatest decline seen in summer (-17% /decade for Baffin Bay, -24% /decade for Davis Strait). Prior to 1980, trends in sea ice decline were small except for the summer season in which linear fits to 1960-2011 time series show declines of -7% /decade for Baffin Bay, and -10% /decade for Davis Strait.

9.0 SUMMARY

Review of relevant literature as well as some new analyses has been presented here to assess trends in oceanic inputs, temperature, salinity and atmospheric properties for Baffin Bay/Davis Strait.

Passages through the Canadian Arctic Archipelago are a principal input into Baffin Bay/Davis Strait, accounting for 2/3 of the freshwater input. Volume and freshwater transports here have high inter-annual variability, but 12 years of moored measurements in Barrow Strait show a downward trend (p=0.12, or 88% confidence) in volume and freshwater transport of about 4% per year from 1999 to 2011. The series is not long enough to conjecture whether this is a long term trend related to climate change, or simply decadal scale variability. Measurements from the other 2 CAA passages are insufficient to establish any phase relationship between the transports through the 3 CAA passages, although recent modeling work (Lu et al., 2013) suggests that the volume transports are in phase.

Water entering Baffin Bay through Barrow Strait is becoming more saline in recent years. Ten years of measurements (2001-2011) at the 150m contour on the south side of Barrow Strait indicate a trend of increasing salinity in annual means of about +0.2 psu/decade at the 40m and 145 m (near-bottom) levels, with 82% and 89% confidence respectively. Trends are higher for summer means; for example, at 40m the late summer trend is +0.5 psu/decade (p=0.04). No trend is observed at 80m depth. There is also a trend (91% confidence) in near-bottom annual mean water temperature of +0.19°/decade with most of the observed warming seen in fall, winter and spring. Since there is a mean eastward flow on the south side of the strait throughout the year, these trends indicate an increase in the salinity and temperature of the water entering Baffin Bay. At Nares Strait, another Baffin Bay input, Munchow et. al. (2011) see warming of +0.23°C/decade, but no trend in salinity.

On the north side of Barrow Strait, there is a trend of increasing salinity in summer at all levels (of varying statistical confidence), with a particularly strong trend in late summer (+0.38 psu/decade in the water column-averaged salinity, p=0.05). There is also a significant warming trend in the mid water column over the early summer to fall period of +0.3 °/decade on the north side, with an increase in the annual mean water column temperature of +0.17°/decade (p=0.09). Since there is little flow at this location except in late summer and fall when the flow is weakly westward, these north side trends reflect changes in conditions in Lancaster Sound and perhaps Baffin Bay. With the observed trends of increasing salinity and temperature presented here being particularly strong in summer which is the biologically active season, there may be associated impacts on this productive ecosystem.

In Barrow Strait there is also observational evidence that the open water period is shifting to earlier in the year. There is a trend of earlier freeze-up on both the North (p=0.04) and South (p=0.07) sides of the strait of about 4 days per year from 1998 to 2009. There is a matching shift to earlier break-up as well, although the statistically reliability of this result is poor because of large scatter in the data.

The northward flowing WGC is another important Davis Strait/Baffin Bay freshwater source. Sparse data quantifies this input at roughly 37 mSv reaching Davis Strait from an original 96 mSv that enters the western North Atlantic at Cape Farewell. The origin of this water is Fram Strait liquid and ice export, that is transported southward down the east coast of Greenland by the EGC and EGCC, and then northward up the west Greenland coast by the WGC. It also includes meteoric water entrained by these coastal flows along the way. The published data are insufficient to identify any trends in this input, or any phase relationship with the CAA input.

A third, and growing Baffin Bay/Davis Strait fresh water input is meteoric water from the Greenland ice sheet. (Canadian glaciers are also rapidly melting but have 10% the mass of the Greenland ice sheet.). Using the Greenland ice sheet mass loss acceleration rate of Rignot et al. (2011), and the drainage distribution defined by Bamber et al. (2012), an increase in meteoric water input into Baffin Bay from a present level of about 8 mSv to 28 mS by 2050 is calculated. The extrapolation of a mass loss acceleration rate which is based on only 18 years of data (1992-2010) to predict glacial input 4 decades in the future is highly speculative. Nonetheless there is evidence to indicate that strong warming in southern Greenland over the last 2 decades and the associated acceleration in glacial melt rate is a response to general Northern Hemispheric warming associated with global warming rather than multi-decadal natural variability (Hanna et al., 2008). Continued acceleration of mass loss might therefore be expected.

An increase in the freshwater input from the Greenland ice sheet and Canadian glaciers will impact the salinity of Baffin Bay/Davis Strait coastal currents. Some of this impact may be offset by reduced freshwater input through the CAA if the observed trend there ends up being something more than decadal variability, but the trend in increased meteoric input is a climate change-induced impact that can more confidently be expected to continue, albeit with large uncertainty in the magnitude of the increase. Based on the estimate of increased ice sheet input outlined above, and an assumption that this new freshwater will be relatively confined within the coastal currents, we calculate a freshening of the upper BIC at Davis Strait of 0.4 psu by 2050. As an extension of the BIC, the upper water of the Labrador Current will in turn see this freshening with possible impacts on Labrador Coast and Grand Banks ecosystems. Over the longer term, the extent to which this growing freshwater input mixes out into the Labrador Sea to affect stratification and therefore the thermohaline circulation remains to be seen.

The analysis of archived time series data presented in this report identifies some trends in T and S properties of the waters of Baffin Bay. Data are relatively sparse and are characterized by high inter-annual variability, but some trends have been identified. In data from the Baffin Island shelf collected over the period 1950 to 2001 there has been freshening in the 50-200m depth range in the second half of this period (1975-2001) of -0.15 psu/decade (p=0.12). There is no discernible trend in the first half of this record. In the top 50m no trend can be identified above the high inter-annual variability seen in that layer.

In intermediate waters of central Baffin Bay, no trend in salinity is observed between 1960 and 2005, but using archived data between 600 and 800m, a significant warming trend of 0.13°C/decade is observed that can account for 40% of the variance in the record variability. This is consistent with the analysis of Zweng and Munchow (2006).

Air temperature records between 1950 and 2011 from 3 stations along the eastern coast of the CAA demonstrate warming, with 2 distinct periods. From 1950 to 1999 there is the suggestion of some slight warming (+0.1, +0.5 and +0.1 ºC/decade for the 3 stations) but the signal is not statistically significant above the observed inter-annual variability. In recent years, the data reveal a sharp increase in temperature at all three stations. From 1999-2011 trends of +2.9, +2.2 and +1.6 ºC/decade are computed for Alert, Pond Inlet and Clyde respectively. The observed warming is greatest at the northern station and weakest at the southern station, but dramatic and significant at all 3 stations.

Fifty-eight year records of annual mean wind speed at Alert and Clyde demonstrate a significant positive trend in wind speed at both stations over the 1954-2011 period shown, although there is strong inter-annual variability particularly at Alert. At Alert this trend is +0.33

$m\cdot s^{-1}$/decade while at Clyde the trend in annual mean wind speed over the last 58 years is +0.58 $m\cdot s^{-1}$/decade.

Time series of annual mean precipitation at Alert and Clyde show strong inter-annual variability, but at Alert a trend of about +10mm/decade is statistically significant over the 60 year record.

Knowledge of recent trends can be insightful in attempting to project future change when assessing and planning for the impacts of anthropogenic climate change. But to be most useful for this purpose, the time series data used need to be long enough to resolve natural variability, which can be on the order of decades. Here, trends in ocean and atmospheric conditions for Baffin Bay/Davis Strait derived from recent and archived data as well as results available in published literature have been presented. Data in this region are sparse, and there are few data time series of sufficient length to resolve some of the longer time scale natural variability associated with the interactions between the ocean and the atmosphere. For example, trends in both the 11 year time series transports through Barrow Strait and the 18 year record of the Greenland ice sheet melt rate presented here are too short to confidently predict conditions 4 decades from now. Inter-annual variability also presents a challenge in extracting statistically significant trends from 10 year records, as some of the results in this report demonstrate. It may also be inappropriate to assume that trends treated as linear based on the analysis of 10 years of data are indeed linear when looking at change over decades, considering the complex interactions in a changing physical environment. But even when data time series are too short to confidently extrapolate for accurate prediction of conditions decades in the future, they can still provide valuable insight when used to identify interconnections between different parameters in the environment. Identified relationships such as the connection between Beaufort Sea winds and transports into Baffin Bay at Lancaster Sound, or the strong connection between sea ice conditions and water temperature in Baffin Bay, improve our understanding of the Arctic ocean-climate system. Such relationships derived from multi-year time series, provide guidance to improve models so that they can be used to more reliably predict future conditions in a rapidly changing environment. Continued long term monitoring of the oceans is critical to that process.

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